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Electron energy distribution in argon electrical discharge

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Electron energy distribution function in argon Townsend discharge l been determined Method of determination is based on the comparis between the experimentally measured values and the calculated valu of the first Townsend ionization coefficient under the assumption of different energy distributions. It is concluded that the electr energy distribution in argon discharge follows the Druyveston's form

1 Introduction

A careful perusal of the literature on gas discharge shows that the theory of Emeleus, Lunt & Meek (1936) is one of the most successful one for the theoretical evaluation of the first Townsend ionization coefficient α/P (α is the first ionization coefficient and P is the gas pressure) from the basic atomic data. This theory gives a rigorous expression (eq (1)) for α/P in which $P_i(V)$ and $F(V)$ are not formally specified

$$\frac{\alpha}{-} = \left(\frac{Ce}{300\,m} \right)^{\frac{1}{2}} \frac{1}{W_e} \int_{V_i}^{\infty} P_i(V) \quad V^{\frac{1}{2}} . F(V) \ dV. \qquad \ldots \quad (1)$$

where e and m are the charge and the rest mass of the electron, C is a constant, W_e is the electron drift velocity, $P_i(V)^+$ is the ionization probability of the gas atoms by direct collision with electrons, $F(v)$ is the electron energy distribution in the gas discharge and V_i is the ionization potential.

Thus if the electron energy distribution is known alongwith electron drift velocity, the ionization cross-section of the gas atoms, and the mean electron energy $\overline{V}$, the value of α/P may be calculated at a particular value of E/P or $\overline{V}$,

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$^+P(v) = 3\ 15Q(v)$, where $Q(v)$ is the ionization crosssection.

(where E is the electric field intensity) In order to calculate the variation of α/P with E/P the variation of the above parameters with E/P must be known Due to the lack of these data, most of the early derivations of α/P were limited only to small ranges of E/P, especially in argon.

Assuming Maxwell's energy distribution for the electrons in the gas discharge, Emeleus, *et al* (1936) applied eq (1) for the calculation of α/P as a function of E/P, using the data they had at hand on V, W_e and $O_i(v)$. Their computed value of α/P in argon were from two to four orders of magnitude higher than the experimental value

The present authors applied eq (1) for the calculation of α/P in argon, assuming Maxwell, & Druyveston (1936) electron energy distribution in the discharge The expressions for α/P derived according to the above two distributions are given below

According to Maxwellian distribuion,

$$\frac{\alpha}{P} = \frac{1\ 23 \times 3\ 15 \times 10^8}{W_c \times (\bar{V})^{3/2}} \int_{V_i}^{\infty} Q_i(V)\ V \exp\left(\frac{-1\ 5V}{\bar{V}}\right)$$

According to Druyveston's form,

$$\frac{\alpha}{P} = \frac{0.6234 \times 3.15 \times 10^8}{W_e \times (\bar{V})^{3/2}} \int_{V_i}^{\infty} Q_i(V)\ V \exp\left(\frac{-0\ 548V^2}{\bar{V}^2}\right) dV \qquad \ldots \quad (3)$$

It is found that the most accurate method for the calculation of α/P, as has indicated also by Emeleus, *et al* (1936) is to carry out the integration of eqs (2) and (3) graphically using the most recently published experimental values of $Q_i(v)$, W_e and $\bar{V}$ (dV is taken to correspond to half electron volt) Two sets of values of α/P have been calculated for each of the above distributions The first set has been calculated by using the published results of $Q_i(v)$ given by Smith (1930) which coincide with the results of Toser *et al* (1960), Tsundi *et al* (1963), The second set has been calculated by using the published results of $Q_i(v)$ of Rapp *et al* (1965) Values of W_e are taken from the results of Golant (1959), which extends upto $E/P = 207v$. cm $^{-1}$ Torr.$^{-1}$

At greater values of E/P, plausible extrapolations have been used for determination of W_e The values of $\bar{V}$ which have been used are those given by Losee (1972) upto $E/P = 193.6$V.cm^{-1} torr^{-1} and for greater values plausible extrapolations have again been used

2 Results and Discussion

The two sets of results of α/P which have been calculated by assuming Druyveston's distribution are shown in Figure 1. The experimental results of α/P

of Heylen *et al* (1968) and that of Kruithof *et al* (1936) are shown also in figure 1 for comparison.

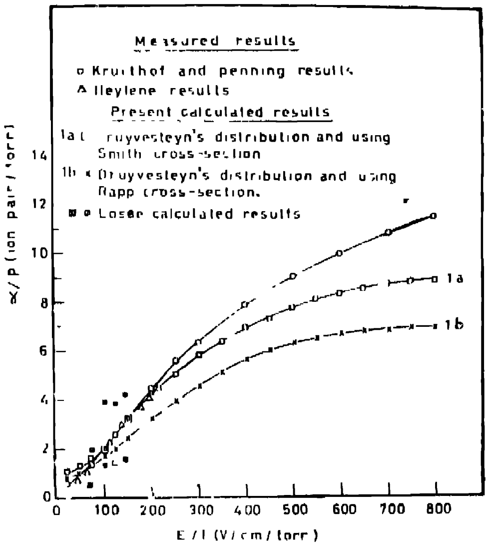

Fig. 1

As can be seen from figure 1, the first set of α/P calculated by using Smith's cross-section (curve 1a) concides with the experimental values in the range of E/P from 75 to 225V.cm^{-1} torr^{-1} which is approximately the range of the experimentally determined values of W_e and V.

In the range of E/P from 25 to 75V.cm^{-1} torr.$^{-1}$ the calculated results are generally higher than the experimental values by not more than 40%. The difference can easily be attributed to the pressure and the purity of the gas used, and also to the gap geometry. It is well known that α/P is a very sensitive function of the above variables Loeb (1955) Kruithof & Penning's (1936) original experimental data on α/P for pure argon shows that, on the average, an increaase in pressure by a factor of 5 increases α/P by 80% for the same value of E/P Heylen (1968) has observed that at an optimum concentration of about 0.66% of ethane in argon, the primary ionization coefficient α/P increased to forty times its value for pure argon. Also Golden & Fisher (1961) observed that in pure argon at $E/P = 7V$.cm^{-1} torr.$^{-1}\alpha/P$ increased by 100% when the gap width was increased by a factor of three Also the accuracy of the experimental results of W_e, V, and $Q_i(v)$, which are functions of the purity of the gas and the method of its measurements, will be reflected in the accuracy of the calculated results of α/P

In the range of E/P from 225 to 800V.cm^{-1} torr.$^{-1}$, the calculated values are lower than the experimental ones by not more than 24% at the highest value of

E/P. As far as the authors are aware, W_c and $\bar{V}$ have not yet been experimentally measured in this range. Therefore, plausible extrapolations are used for the prediction of the values of the above two parameters, which are used in the calculation of α/P. Despite the gradual deviation of the calculated results from the measured values of α/P in this range of E/P, however, on the whole, curve (1a) has the same shape as the experimental curves.

Curve (1b) is calculated for the same values of W_c and V, and the same Druyveston distribution, but using the ionization cross-section of Rapp & Golden (1965) which is lower than any measured cross-section by 30% at maximum cross-section. Though the values of this curve (Ib) are generally lower (at maximum 40%) than the experimental results but it has the general shape as the experimental curves.

Figure 1 shows also the values of α/P calculated by Losee (1972), using their experimentally determined energy distribution, ionization cross-section of Rapp-Golden (1965), and two different predetermined diffusion cross-sections.

II. Figure 2 curve (2a) shows the calculated values of α/P as a function of E/P using the Maxwellian distribution. It is clear that the curve (2a) does not have the same shape as the experimental curve The calculated results in the range of E/P $<100\text{V.cm}^{-1}$ torr^{-1} show a more gradual increase than the experimental ones as E/P is decreases. At $E/A = 50\text{V.cm}^{-1}\ \text{torr}^{-1}$, the calculated value of

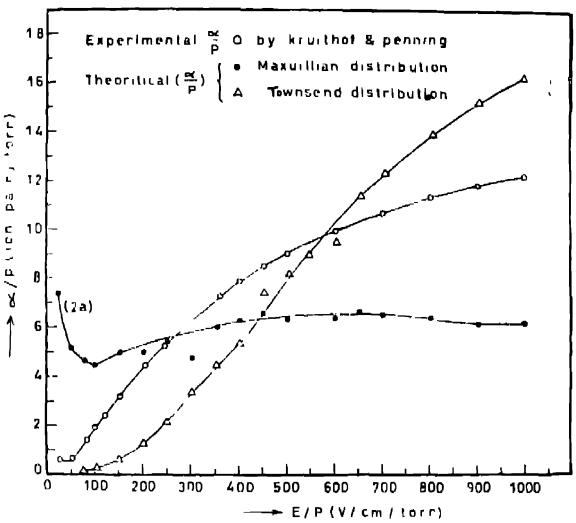

Fig. 2

α/P is about one order of magnitude higher than the experimental value. The same tendency appears in the work of Emeleus, *et al* (1936). Finally it has been found that the curve of α/P calculated by using the Townsend's distribution (1930) also does not have the same shape as the experimental curves, as can be seen clearly from figure 2b

3 Conclusion

The experimental and calculated values of α/P-according to Druyveston distribution—coincide with each other in the range of E/P from 75 to 225V cm^{-1} torr^{-1} while it shows discrepancies in the ranges of E/P from 25-75V.cm^{-1} torr^{-1} and 225-800 V cm^{-1} torr.$^{-1}$ These discrepancies are not greater than 40% in the lower range and 24% in the upper range and are attributed to the pressure and purity of the gas and also to the geometry of the discharge gap On the whole it is found that the experimental curve has the same shape as the calculated one.

Concerning Maxwell and Townsend distribution, not only the calculated results show greater discrepancies but also they do not have the same shape as the experimental ones

This work lends support to the hypothesis that the electron energy distribution in argon Townsend discharge follows that of the Druyveston's form.

References

Asundi R. K. & M V Kurepa 1963 *J Electronics and Control*, GB, **15**, 40

Druyveston M. J 1936 *Physica*, **3**, 65.

Emeleus K G., Lunt, R W & C. A Meek 1936 *Proc Roy Soc* **A156**, 394.

Golant V E. 1959 *Soviet Phys Tech. Phys* **4**, 680

Golden D. E. & L. H Fisher 1961 *Phys Rev* **123**, 1079

Heylen A. E. D. 1968 *Brit J Appl Phys* **1**, 179

Kruithof A. A. & F. M Penning, 1936 *Physica* **4**, 430

Losee J. R 1972 *Univ. Microfilms An Arbor, Mich USA*, 72, 3854

Loeb L. B. 1955 *Basic Process of Gaseous Electronics, University of California Press*

Rapp D & P Englander-Golden 1965, *J Chem. Phys.* **43**, 1964

Rapp D & P Englander-Golden 1965 *J Chem. Phys* **43**, 1964.

Smith P T 1930 *Phys Rev* **36**, 1293.

Schram B L., de Heer F J, Vanver Wiel M J. and J Kistemaker 1969, *Physica* **31**, 94.

Townsend J. S 1930 *Phil Mag* **9**, 1145.

Toser B A. & J. D Craggs 1960 *J Electron* **8**, 103